Top, Higgs, Diboson and Electroweak Fit to the Standard Model Effective Field Theory

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Based on 2012.02779 J. Ellis, MM, K. Mimasu, V. Sanz, T. You

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Higgs and Effective Field Theory 2021

The Standard Model Effective Field Theory

Powerful tool for capturing deviations from the SM and performing indirect searches for new physics.

Model independent: assume the BSM physics is heavy

$$E << \Lambda$$

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{C_i}{\Lambda^2}\mathcal{O}_i + \ldots$$

We restrict to dimension-6 operators.

The Standard Model Effective Field Theory

Warsaw basis
[1008.4884
Grzadkowski et. al]

X^3		H^6 and H^4D^2		ψ^2H^3	
$\mathcal{O}_G$	$f^{ABC}G_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$	$\mathcal{O}_H$	$(H^\dagger H)^3$	$\mathcal{O}_{eH}$	$(H^\dagger H)(\bar{l}_p e_r H)$
$\mathcal{O}_{\widetilde{G}}$	$f^{ABC}\widetilde{G}_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$	$\mathcal{O}_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$	$\mathcal{O}_{uH}$	$(H^\dagger H)(\bar{q}_p u_r \widetilde{H})$
$\mathcal{O}_W$	$\varepsilon^{IJK}W_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$	$\mathcal{O}_{HD}$	$\left(H^\dagger D^\mu H\right)^\star\left(H^\dagger D_\mu H\right)$	$\mathcal{O}_{dH}$	$(H^\dagger H)(\bar{q}_p d_r H)$
$\mathcal{O}_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$				

X^2H^2		ψ^2XH		ψ^2H^2D	
$\mathcal{O}_{HG}$	$H^\dagger H\, G^A_{\mu\nu}G^{A\mu\nu}$	$\mathcal{O}_{eW}$	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I H W^I_{\mu\nu}$	$\mathcal{O}_{Hl}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_p\gamma^\mu l_r)$
$\mathcal{O}_{H\widetilde{G}}$	$H^\dagger H\, \widetilde{G}^A_{\mu\nu}G^{A\mu\nu}$	$\mathcal{O}_{eB}$	$(\bar{l}_p\sigma^{\mu\nu}e_r)H B_{\mu\nu}$	$\mathcal{O}_{Hl}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$\mathcal{O}_{HW}$	$H^\dagger H\, W^I_{\mu\nu}W^{I\mu\nu}$	$\mathcal{O}_{uG}$	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{H}\, G^A_{\mu\nu}$	$\mathcal{O}_{He}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_p\gamma^\mu e_r)$
$\mathcal{O}_{H\widetilde{W}}$	$H^\dagger H\, \widetilde{W}^I_{\mu\nu}W^{I\mu\nu}$	$\mathcal{O}_{uW}$	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{H}\, W^I_{\mu\nu}$	$\mathcal{O}_{Hq}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}_p\gamma^\mu q_r)$
$\mathcal{O}_{HB}$	$H^\dagger H\, B_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{uB}$	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{H}\, B_{\mu\nu}$	$\mathcal{O}_{Hq}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{q}_p\tau^I\gamma^\mu q_r)$
$\mathcal{O}_{H\widetilde{B}}$	$H^\dagger H\, \widetilde{B}_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{dG}$	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)H\, G^A_{\mu\nu}$	$\mathcal{O}_{Hu}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}_p\gamma^\mu u_r)$
$\mathcal{O}_{HWB}$	$H^\dagger\tau^I H\, W^I_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{dW}$	$(\bar{q}_p\sigma^{\mu\nu}d_r)\tau^I H\, W^I_{\mu\nu}$	$\mathcal{O}_{Hd}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p\gamma^\mu d_r)$
$\mathcal{O}_{H\widetilde{W}B}$	$H^\dagger\tau^I H\, \widetilde{W}^I_{\mu\nu}B^{\mu\nu}$	$\mathcal{O}_{dB}$	$(\bar{q}_p\sigma^{\mu\nu}d_r)H\, B_{\mu\nu}$	$\mathcal{O}_{Hud}$	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}_p\gamma^\mu d_r)$

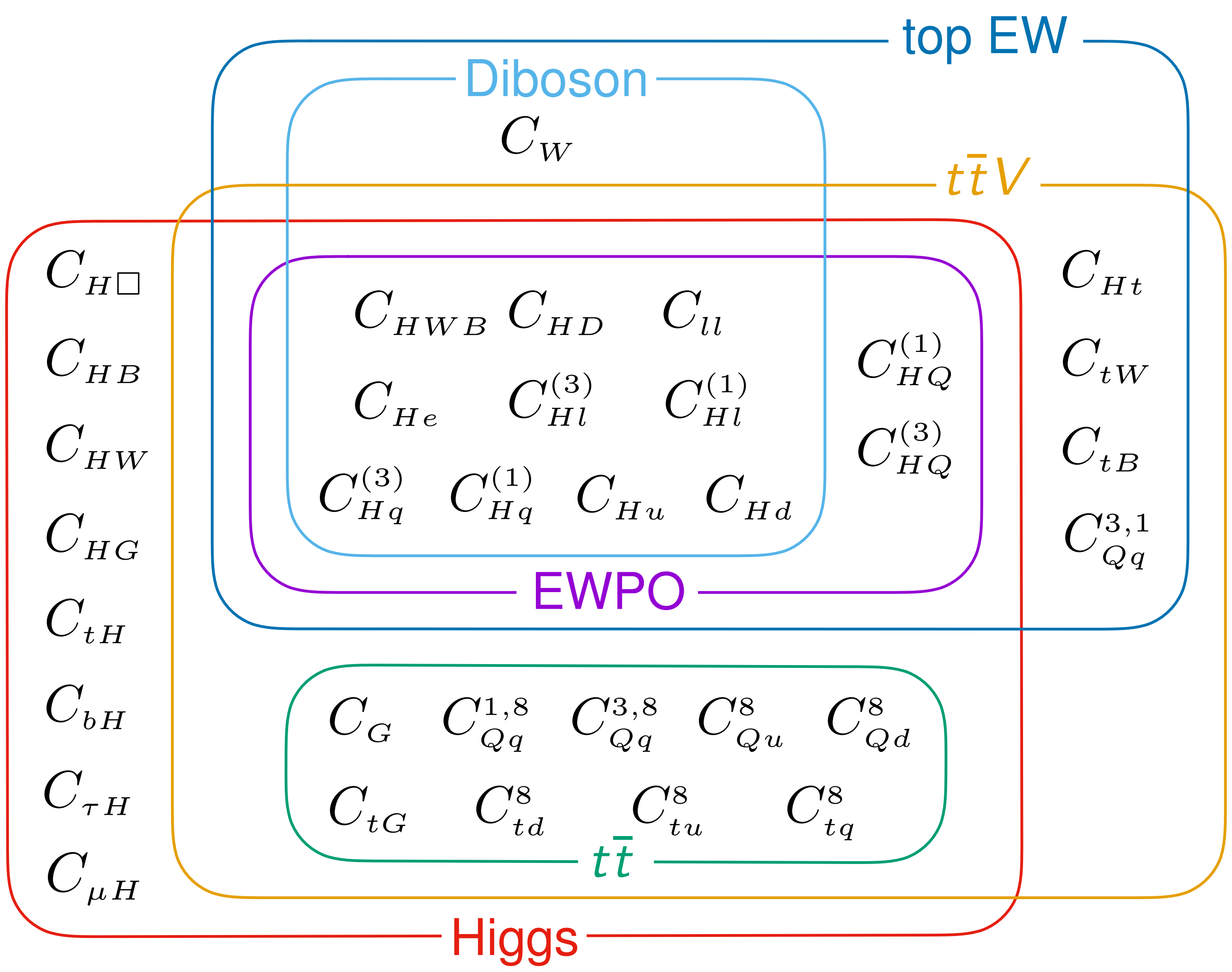
$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
$\mathcal{O}_{ll}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	$\mathcal{O}_{ee}$	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	$\mathcal{O}_{le}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$\mathcal{O}_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	$\mathcal{O}_{uu}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$	$\mathcal{O}_{lu}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
$\mathcal{O}_{qq}^{(3)}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	$\mathcal{O}_{dd}$	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$	$\mathcal{O}_{ld}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$\mathcal{O}_{lq}^{(1)}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	$\mathcal{O}_{eu}$	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$	$\mathcal{O}_{qe}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$\mathcal{O}_{lq}^{(3)}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	$\mathcal{O}_{ed}$	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$	$\mathcal{O}_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
		$\mathcal{O}_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$\mathcal{O}_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$\mathcal{O}_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$\mathcal{O}_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
				$\mathcal{O}_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating	
$\mathcal{O}_{ledq}$	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	$\mathcal{O}_{duq}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$
$\mathcal{O}_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\varepsilon_{jk}(\bar{q}_s^k d_t)$	$\mathcal{O}_{qqu}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$
$\mathcal{O}_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r)\varepsilon_{jk}(\bar{q}_s^k T^A d_t)$	$\mathcal{O}_{qqq}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$\mathcal{O}_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\varepsilon_{jk}(\bar{q}_s^k u_t)$	$\mathcal{O}_{duu}$	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$
$\mathcal{O}_{lequ}^{(3)}$	$(\bar{l}_p^j\sigma_{\mu\nu}e_r)\varepsilon_{jk}(\bar{q}_s^k\sigma^{\mu\nu}u_t)$		

A global fit to the SMEFT

Each operator contributes to multiple datasets

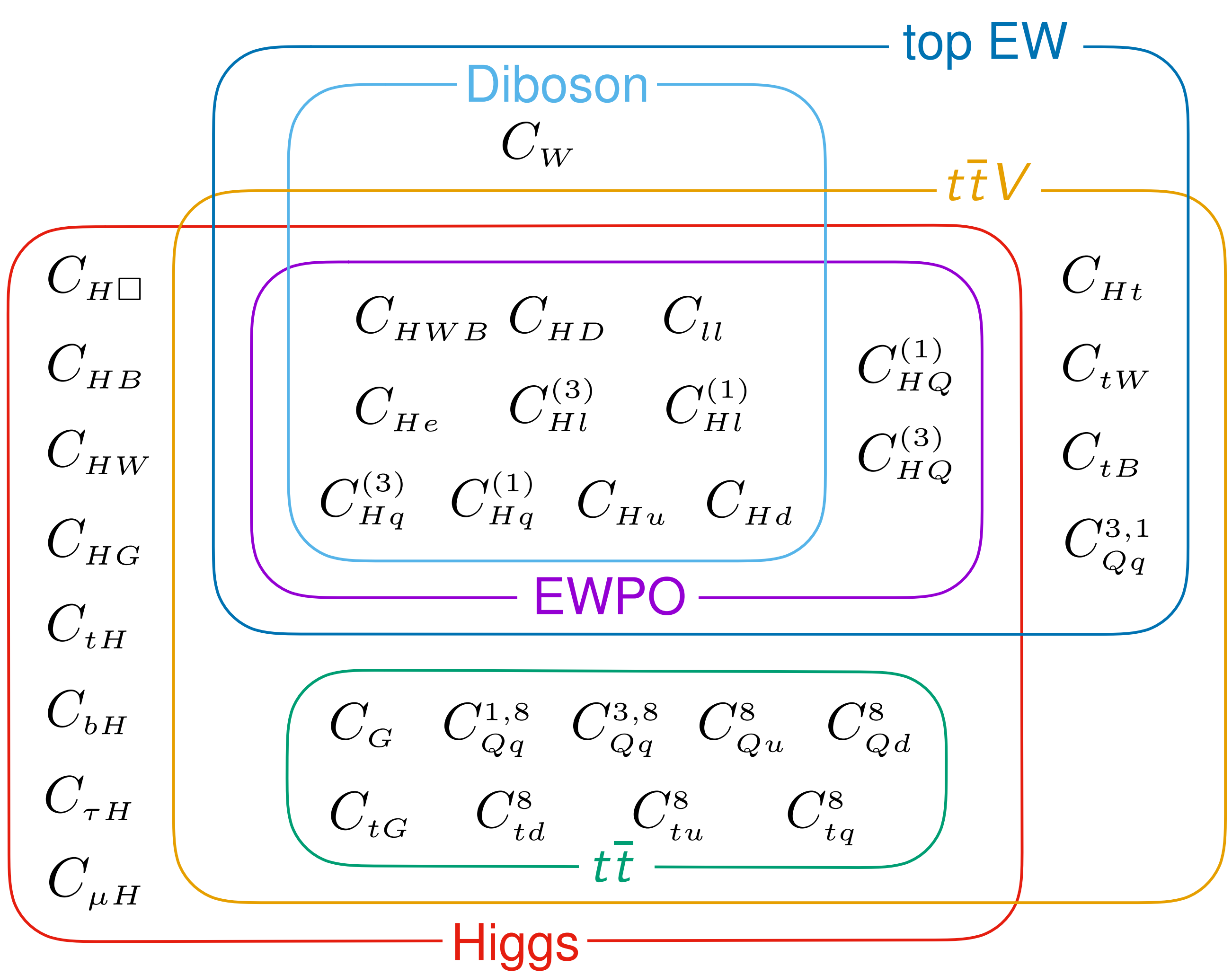
- expect an interplay between sectors



A global fit to the SMEFT

This highlights the need for a **global fit** to understand and parameterise the deviations and correlations between operators and sectors.

We include data from top, diboson, Higgs and EWPO in a fit to 34 dim-6 operators.



SMEFT conventions

- Warsaw basis
- Neglect CP-violating operators
- Two flavour scenarios:

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_i \frac{C_i}{\Lambda^2}\mathcal{O}_i$$

  - Flavour universal $SU(3)^5$
  - Top-specific flavour scenario singles out top couplings *[1802.07237]*

$$SU(3)^5 \to SU(2)_q \times SU(2)_u \times SU(3)_d \times SU(3)_l \times SU(3)_e$$

In both flavour scenarios we also include 4 Yukawa operators which explicitly break these flavour symmetries:

$$\mathcal{O}_{\tau H}, \mathcal{O}_{\mu H}, \mathcal{O}_{bH}, \mathcal{O}_{tH}$$

Measurements

- 341 statistically independent measurements
- Correlation information included from published covariance matrices

Higgs: 72

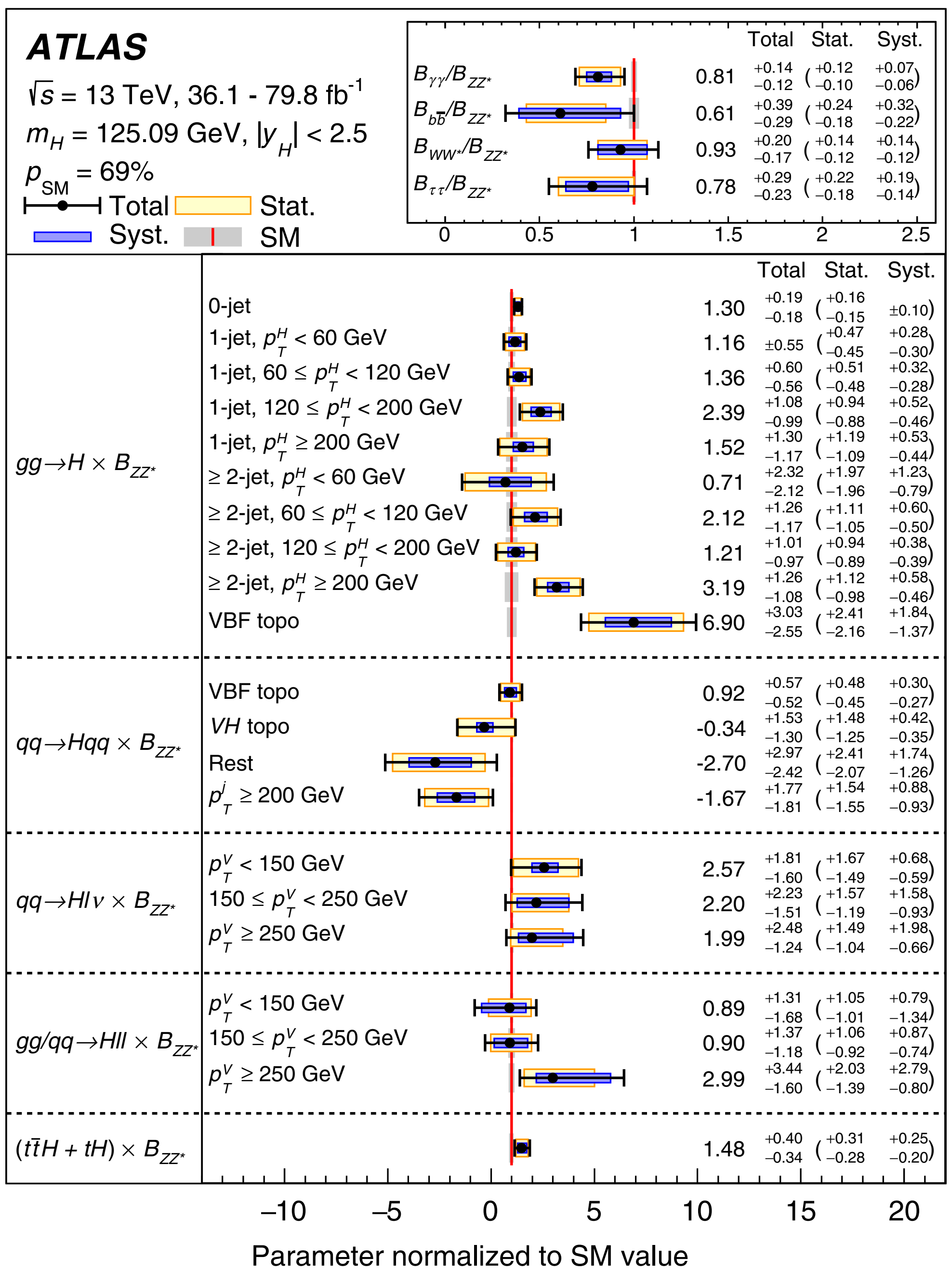
- Signal strength combinations (LHC Run 1 and Run 2)
- STXS combination (LHC Run 2)
- Measurements of

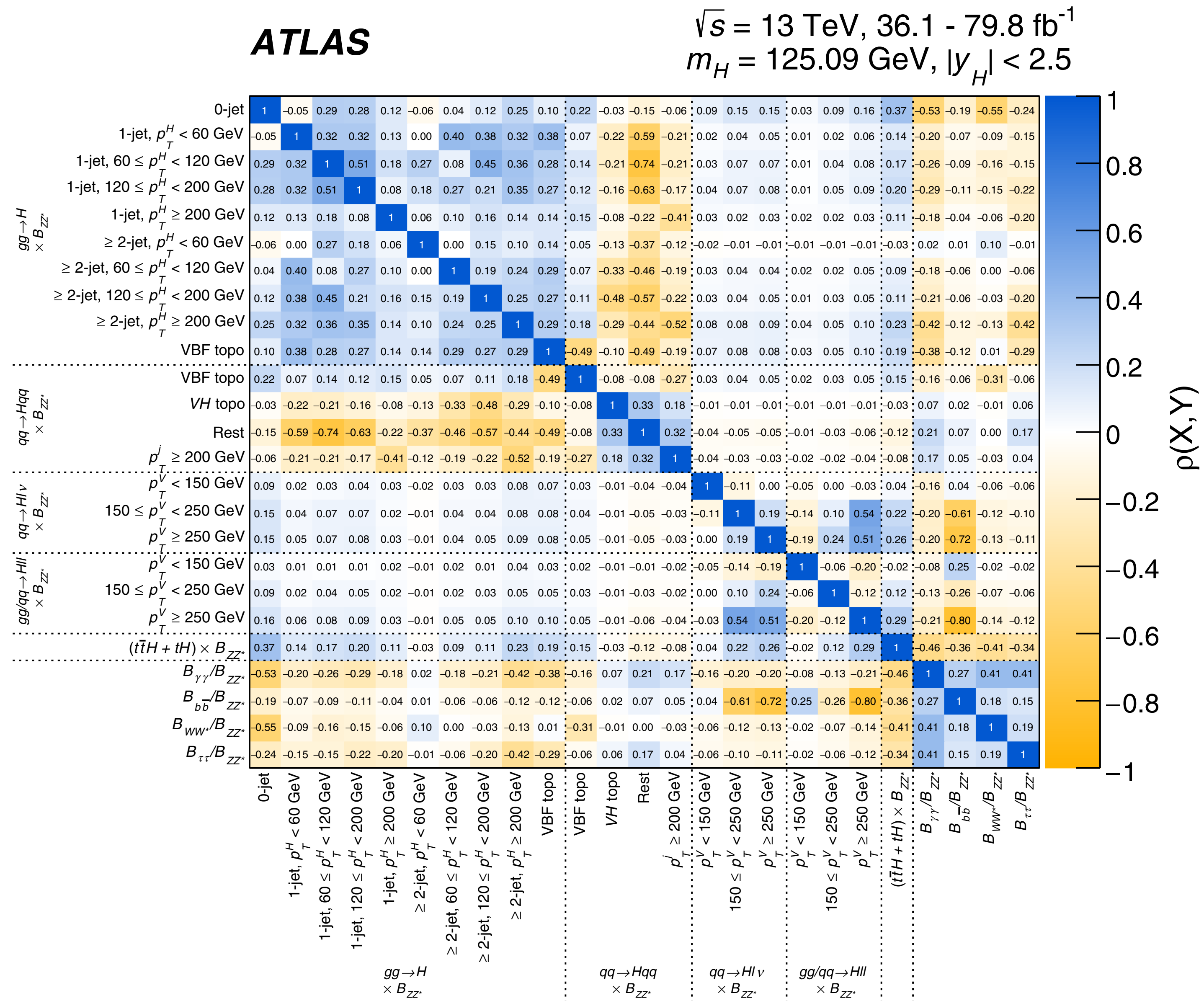
$H \to Z\gamma$ $\quad H \to \mu\mu$

Higgs STXS data from LHC Run 2 ATLAS

ATLAS Run 2 STXS combination *[HIGG-2018-57, Phys. Rev. D 101 (2020) 012002]*

A total of 21 STXS bins with published correlation matrix





Measurements

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- Measurements of

$$H \to Z\gamma \qquad H \to \mu\mu$$

EWPO: 14

LEP, Tevatron, LHC measurements

$$\{\Gamma_Z, \sigma^0_{\text{had.}}, R^0_l, A^l_{FB}, A_l, R^0_b, R^0_c, A^b_{FB}, A^c_{FB}, A_b, A_c, M_W\}\,.$$

Diboson: 118

- LHC and LEP measurements of

$$WW, WZ, Zjj$$

Top: 137

LHC measurements of

$$t\bar{t}, \quad t\bar{t}+V, \quad \text{single top}$$

Fitting methodology

$$\chi^2(C_i) = (\vec{y} - \vec{\mu}(C_i))^T V^{-1} (\vec{y} - \vec{\mu}(C_i))$$

$\vec{y}$: vector of observables with covariance matrix V

Predictions: $\mu_\alpha(C_i) = \mu_\alpha^{SM} + H_{\alpha i} C_i$

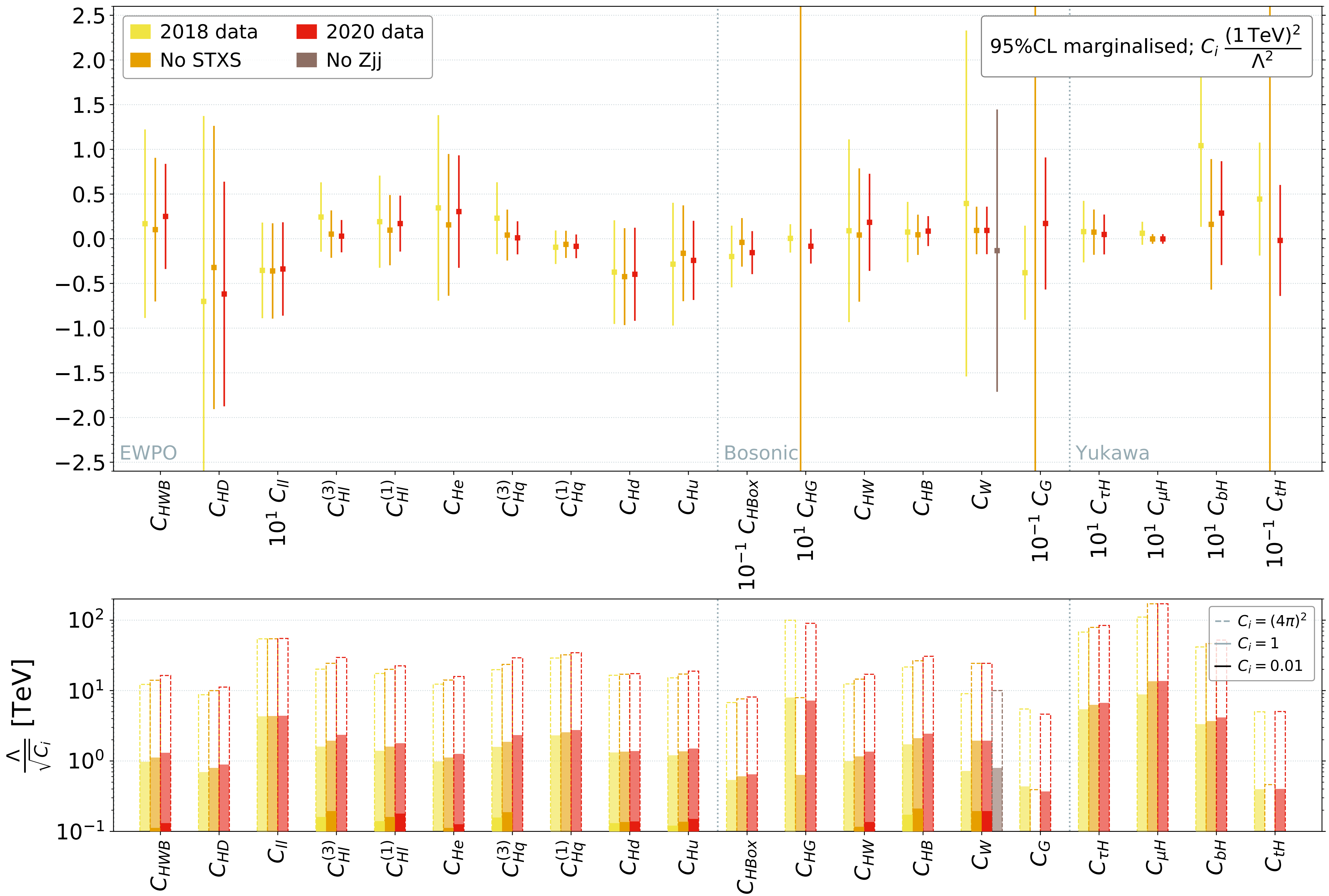
i.e. restricting to $\mathcal{O}(\Lambda^{-2})$ in the EFT expansion

Best-fit WC: $\hat{\vec{C}} = (H^T V^{-1} H)^{-1} H^T V^{-1} (\vec{y} - \vec{\mu}^{SM})$

Covariance: $U = (H^T V^{-1} H)^{-1} = F^{-1}$

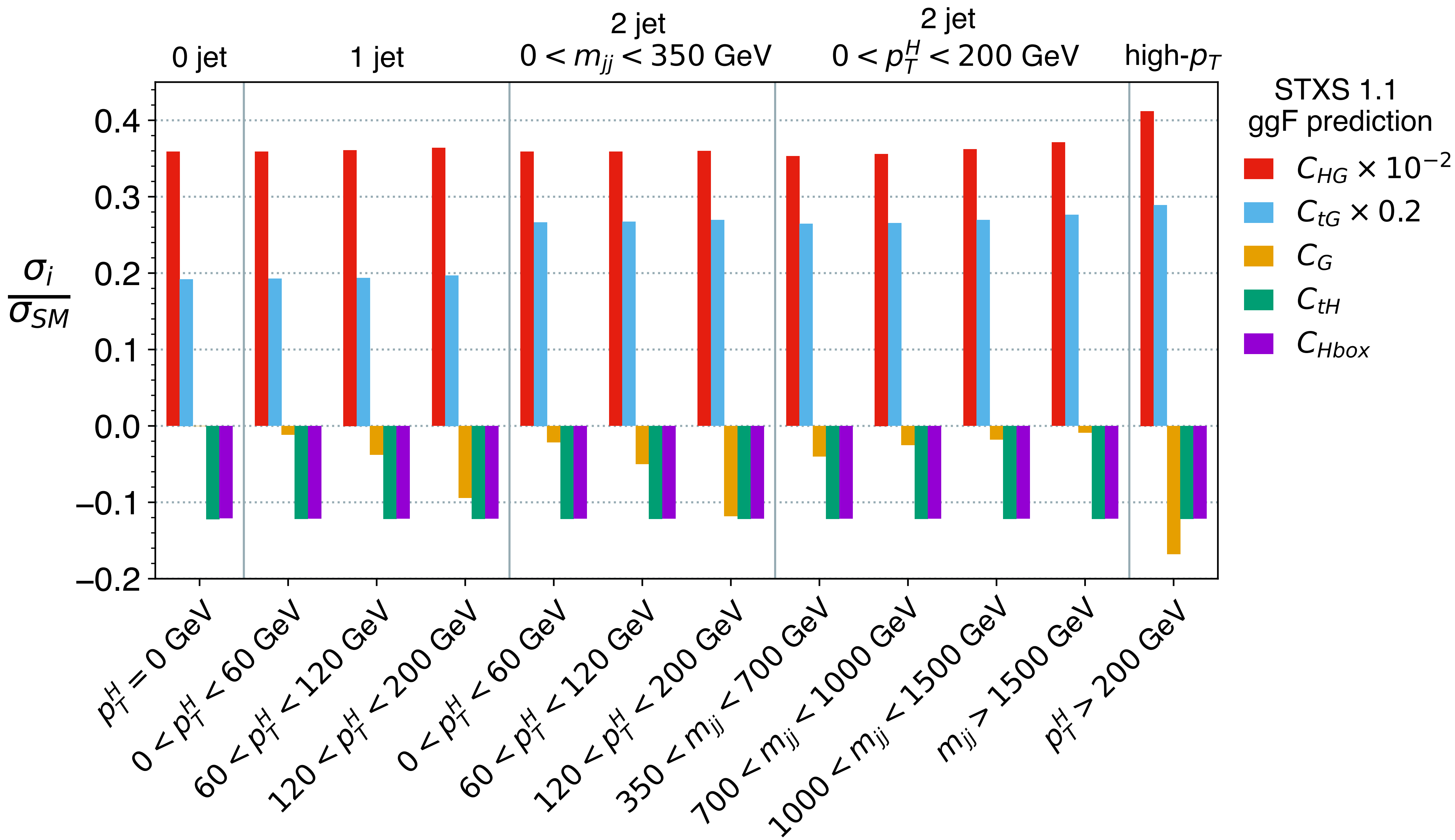
(Fisher information)

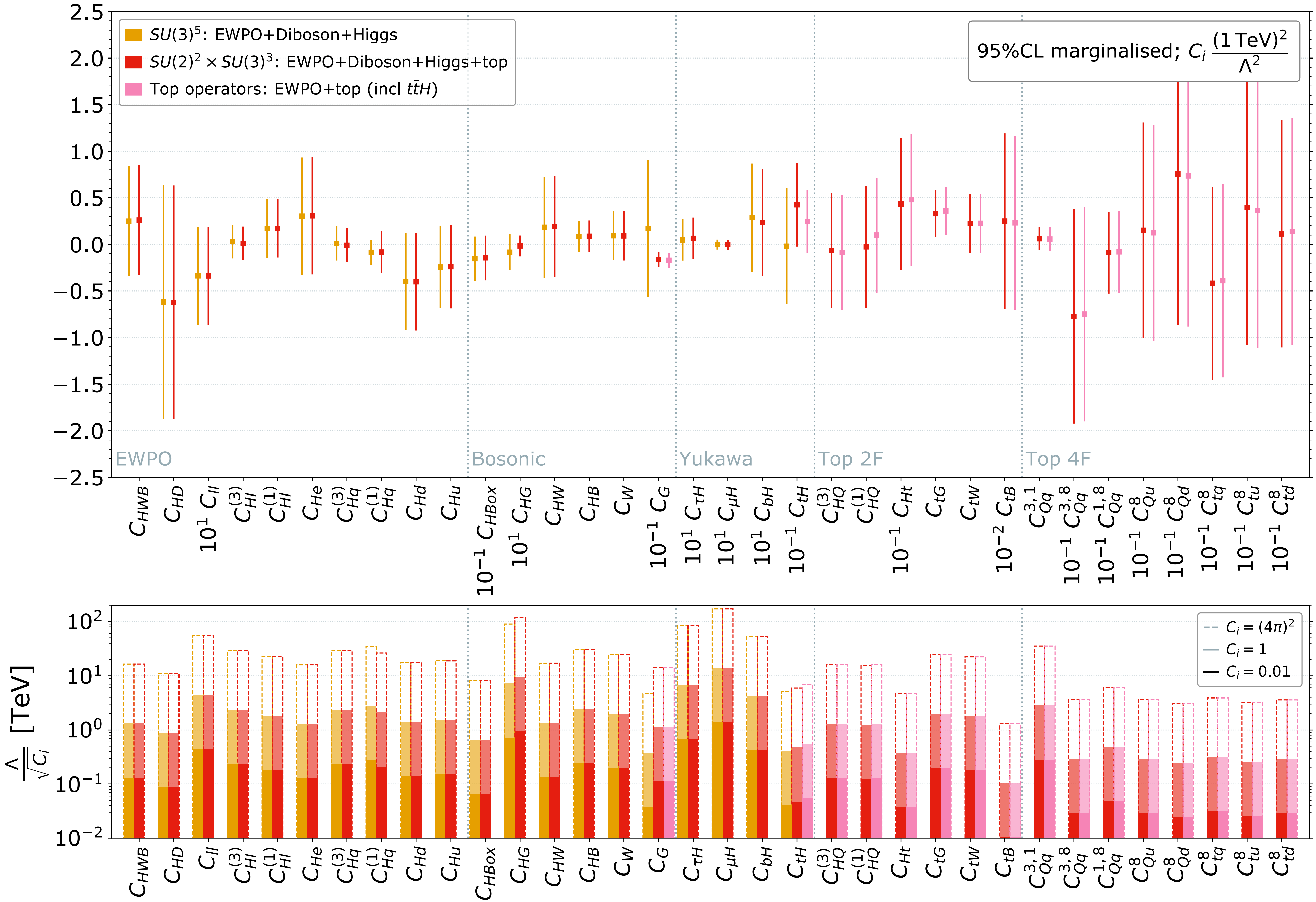
Fit to Higgs, diboson, electroweak data in the flavour universal scenario:



STXS measurements for ggF

STXS measurements of gluon gluon fusion **improve sensitivity** and **break degeneracy** between SMEFT operators:





$SU(3)^5$: EWPO+Diboson+Higgs
$SU(2)^2 \times SU(3)^3$: EWPO+Diboson+Higgs+top
Top operators: EWPO+top (incl $t\bar{t}H$)
95%CL marginalised; $C_i \frac{(1\,\text{TeV})^2}{\Lambda^2}$
EWPO
Bosonic
Yukawa
Top 2F
Top 4F
$C_i = (4\pi)^2$
$C_i = 1$
$C_i = 0.01$
$\frac{\Lambda}{\sqrt{C_i}}$ [TeV]

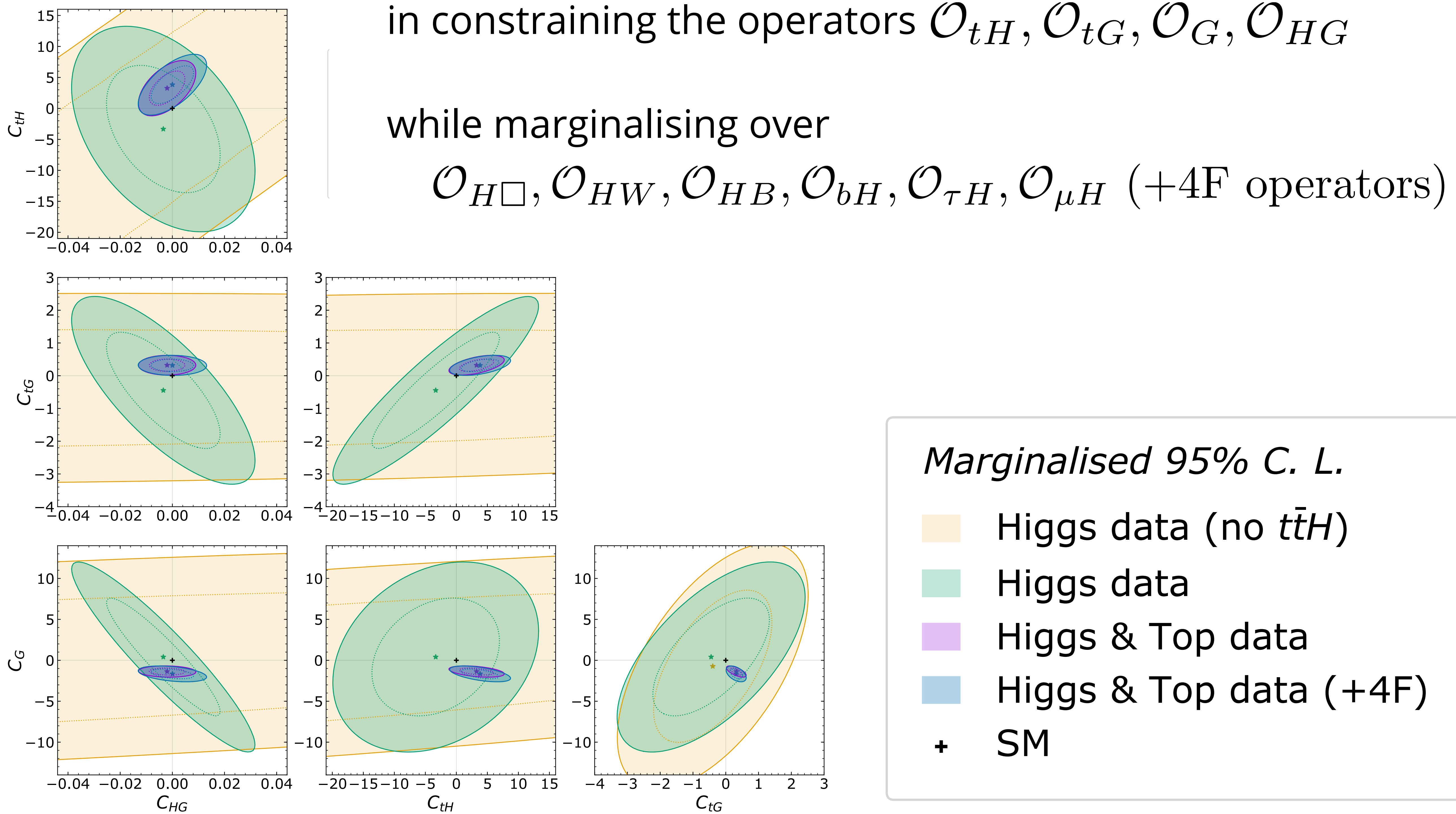
Top-Higgs interplay

Studying the interplay of Higgs and top data

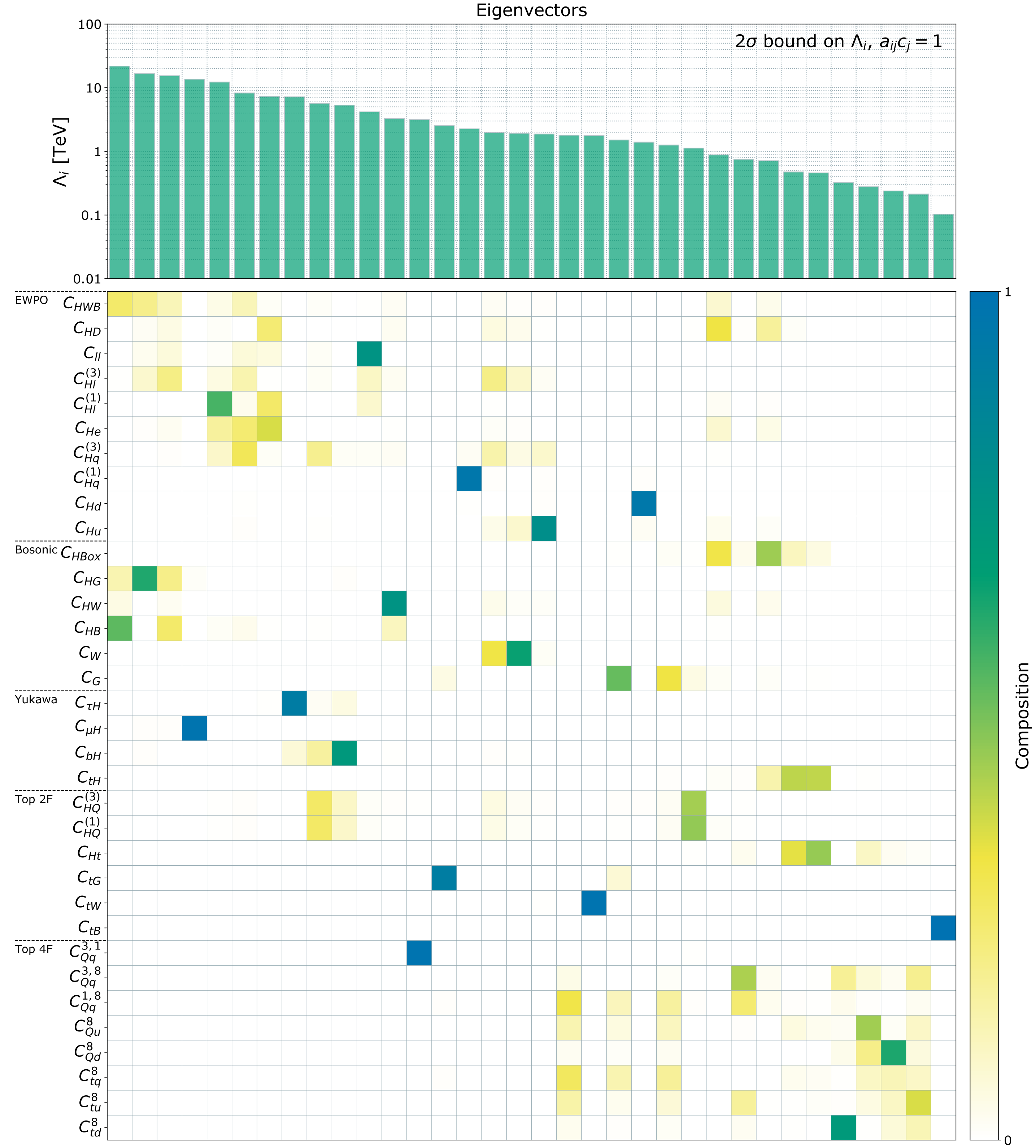
in constraining the operators $\mathcal{O}_{tH}, \mathcal{O}_{tG}, \mathcal{O}_{G}, \mathcal{O}_{HG}$

while marginalising over

$\mathcal{O}_{H\Box}, \mathcal{O}_{HW}, \mathcal{O}_{HB}, \mathcal{O}_{bH}, \mathcal{O}_{\tau H}, \mathcal{O}_{\mu H}$ (+4F operators)



Principal Component Analysis



EWPO	6	35	59	–	99	97	99	–	73	25	75	–	–	–	91	8	8	60	–	–	–	90	–	–	3	–	3	1	–	–	–	–	–	–
LEP WW	–	–	–	–	–	–	–	–	–	–	24	–	–	–	2	9	3	8	–	–	–	6	–	–	5	–	4	–	–	–	–	–	–	–
Run 1, μ_H	15	13	7	5	–	–	–	21	2	7	–	6	–	1	1	6	3	3	–	–	–	–	1	–	25	–	12	10	6	–	–	–	–	–
Run 2, μ_H	29	28	16	94	–	–	–	45	5	17	–	90	–	14	2	14	6	5	–	–	8	–	11	2	37	2	30	26	17	–	–	–	–	–
STXS	50	23	18	1	–	–	–	33	19	50	–	2	–	6	3	24	11	17	–	–	4	1	4	–	12	–	19	12	8	–	–	–	–	–
LHC WW	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6	1	3	–	–	–	–	–	–	9	–	4	–	–	–	–	–	–	–
LHC Zjj	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	30	66	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
$t\bar{t}$	–	–	–	–	–	–	–	–	–	–	–	–	–	71	–	1	–	–	99	84	72	–	72	10	7	12	19	11	27	97	98	100	99	1
single top	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–	2	1	–	–	14	–	1	2	76	1	6	–	6	8	–	–	–	–	96
$t\bar{t}V$	–	–	–	–	–	–	–	–	–	–	–	–	–	8	–	–	–	–	–	–	15	–	9	10	–	79	8	31	33	3	–	–	–	–

Relative constraining power (%)

UV models

We analyse our fit in terms of a set of BSM benchmark models

from *2009.01249 Marzocca et. al, 1711.10391 de Blas et. al*

Name	Spin	SU(3)	SU(2)	U(1)	Name	Spin	SU(3)	SU(2)	U(1)
S	0	1	1	0	Δ_1	$\frac{1}{2}$	1	2	$-\frac{1}{2}$
S_1	0	1	1	1	Δ_3	$\frac{1}{2}$	1	2	$-\frac{1}{2}$
φ	0	1	2	$\frac{1}{2}$	Σ	$\frac{1}{2}$	1	3	0
Ξ	0	1	3	0	Σ_1	$\frac{1}{2}$	1	3	-1
Ξ_1	0	1	3	1	U	$\frac{1}{2}$	3	1	$\frac{2}{3}$
B	1	1	1	0	D	$\frac{1}{2}$	3	1	$-\frac{1}{3}$
B_1	1	1	1	1	Q_1	$\frac{1}{2}$	3	2	$\frac{1}{6}$
W	1	1	3	0	Q_5	$\frac{1}{2}$	3	2	$-\frac{5}{6}$
W_1	1	1	3	1	Q_7	$\frac{1}{2}$	3	2	$\frac{7}{6}$
N	$\frac{1}{2}$	1	1	0	T_1	$\frac{1}{2}$	3	3	$-\frac{1}{3}$
E	$\frac{1}{2}$	1	1	-1	T_2	$\frac{1}{2}$	3	3	$\frac{2}{3}$
T	$\frac{1}{2}$	3	1	$\frac{2}{3}$	TB	$\frac{1}{2}$	3	2	$\frac{1}{6}$

UV models: patterns

We analyse our fit in terms of a set of BSM benchmark models from *2009.01249 Marzocca et. al, 1711.10391 de Blas et. al*

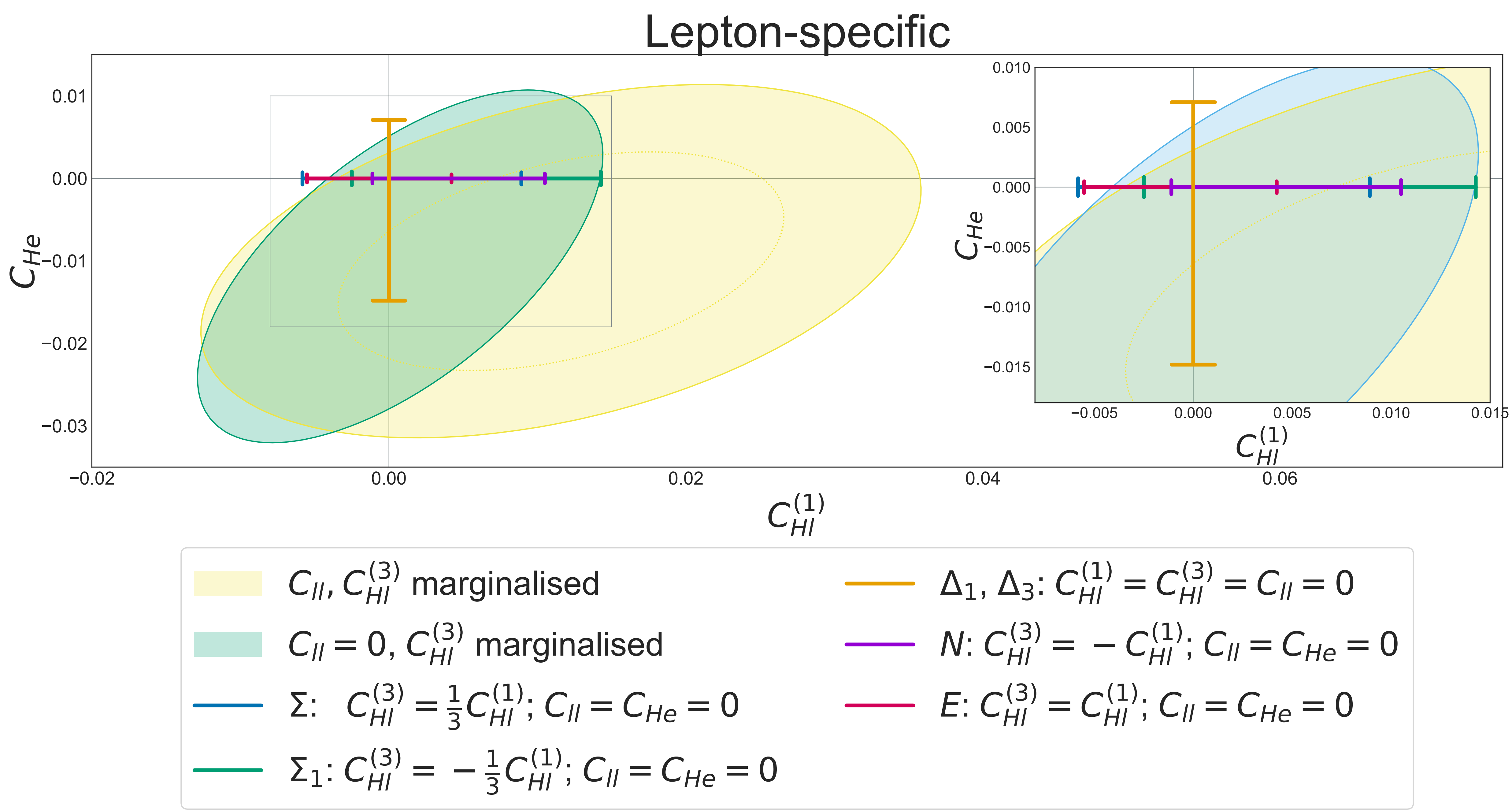
Some models exhibit similar patterns among operators

- Consider models with couplings to leptons: $N, E, \Delta_1, \Delta_3, \Sigma, \Sigma_1$
- These will generate

$$\mathcal{O}_{Hl}^{(1)}, \mathcal{O}_{Hl}^{(3)}, \mathcal{O}_{He}, \mathcal{O}_{ll}$$

with patterns such as $C_{Hl}^{(1)} \propto C_{Hl}^{(3)}$ and $C_{ll} \propto C_{He}$

UV models: patterns



See 2012.02779 for quark-specific, top-specific and boson-specific cases

Conclusions

- Global fit produced using **`Fitmaker`**:

  a publicly available python code
  https://gitlab.com/kenmimasu/fitrepo
  (Version for public use still to come!)

- an adaptable, flexible and extensible framework for performing global SMEFT fits.

Thank you for listening!

Backup

Datasets: Higgs

LHC Run 1 Higgs	$n_{\mathbf{obs}}$	**Ref.**
ATLAS and CMS LHC Run 1 combination of Higgs signal strengths. Production: ggF, VBF, ZH, WH & ttH Decay: $\gamma\gamma$, ZZ, W^+W^-, $\tau^+\tau^-$ & $b\bar{b}$	21	[8]
ATLAS inclusive $Z\gamma$ signal strength measurement	1	[9]

LHC Run 2 Higgs (new)	$n_{\mathbf{obs}}$	**Ref.**
ATLAS combination of signal strengths and stage 1.0 STXS in $H \to 4\ell$ including ratios of branching fractions to $\gamma\gamma$, WW^*, $\tau^+\tau^-$ & $b\bar{b}$ Signal strengths|coarse STXS bins| fine STXS bins	16|19|25	[10]
CMS LHC combination of Higgs signal strengths. Production: ggF, VBF, ZH, WH & ttH Decay: $\gamma\gamma$, ZZ, W^+W^-, $\tau^+\tau^-$, $b\bar{b}$ & $\mu^+\mu^-$	23	[11]
CMS stage 1.0 STXS measurements for $H \to \gamma\gamma$. 13 parameter fit | 7 parameter fit	13|7	[12]
CMS stage 1.0 STXS measurements for $H \to \tau^+\tau^-$	9	[13]
CMS stage 1.1 STXS measurements for $H \to 4\ell$	19	[14]
CMS differential cross section measurements of inclusive Higgs production in the $WW^* \to \ell\nu\ell\nu$ final state. $\frac{d\sigma}{dn_{\text{jet}}}$ | $\frac{d\sigma}{dp_H^T}$	5|6	[15]
ATLAS $H \to Z\gamma$ signal strength.	1	[16]
ATLAS $H \to \mu^+\mu^-$ signal strength.	1	[17]

EW precision observables	$n_{\mathbf{obs}}$	**Ref.**
Precision electroweak measurements on the Z resonance. Γ_Z, $\sigma^0_{\mathrm{had.}}$, R^0_ℓ, A^ℓ_{FB}, $A_\ell(\mathrm{SLD})$, $A_\ell(\mathrm{Pt})$, R^0_b, R^0_c A^b_{FB}, A^c_{FB}, A_b & A_c	12	[1]
Combination of CDF and D0 W-Boson Mass Measurements	1	[6]
LHC run 1 W boson mass measurement by ATLAS	1	[57]

Diboson LEP & LHC	$n_{\mathbf{obs}}$	**Ref.**
W^+W^- angular distribution measurements at LEP II.	8	[5]
W^+W^- total cross section measurements at L3 in the $\ell\nu\ell\nu$, $\ell\nu qq$ & $qqqq$ final states for 8 energies	24	[3]
W^+W^- total cross section measurements at OPAL in the $\ell\nu\ell\nu$, $\ell\nu qq$ & $qqqq$ final states for 7 energies	21	[4]
W^+W^- total cross section measurements at ALEPH in the $\ell\nu\ell\nu$, $\ell\nu qq$ & $qqqq$ final states for 8 energies	21	[2]
ATLAS W^+W^- differential cross section in the $e\nu\mu\nu$ channel, $\frac{d\sigma}{dp^T_{\ell_1}}$, $p_T > 120$ GeV overflow bin	1	[66]
ATLAS W^+W^- fiducial differential cross section in the $e\nu\mu\nu$ channel, $\frac{d\sigma}{dp^T_{\ell_1}}$	14	[70]
ATLAS $W^\pm Z$ fiducial differential cross section in the $\ell^+\ell^-\ell^\pm\nu$ channel, $\frac{d\sigma}{dp^T_Z}$	7	[69]
CMS $W^\pm Z$ normalised fiducial differential cross section in the $\ell^+\ell^-\ell^\pm\nu$ channel, $\frac{1}{\sigma}\frac{d\sigma}{dp^T_Z}$	11	[67]
ATLAS Zjj fiducial differential cross section in the $\ell^+\ell^-$ channel, $\frac{d\sigma}{d\Delta\varphi_{jj}}$	12	[71]

Datasets: top

Tevatron & Run 1 top	n_{obs}	**Ref.**
Tevatron combination of differential tt̄ forward-backward asymmetry, $A_{FB}(m_{t\bar{t}})$.	4	[7]
ATLAS $t\bar{t}$ differential distributions in the dilepton channel. $\frac{d\sigma}{dm_{t\bar{t}}}$	6	[18]
ATLAS $t\bar{t}$ differential distributions in the ℓ+jets channel. $\frac{d\sigma}{dm_{t\bar{t}}}$ | $\frac{d\sigma}{d\|y_{t\bar{t}}\|}$ | $\frac{d\sigma}{dp_t^T}$ | $\frac{d\sigma}{d\|y_t\|}$.	7|5|8|5	[19]
CMS $t\bar{t}$ differential distributions in the ℓ+jets channel. $\frac{d\sigma}{dm_{t\bar{t}}}$ | $\frac{d\sigma}{dy_{t\bar{t}}}$ | $\frac{d\sigma}{dp_t^T}$ | $\frac{d\sigma}{dy_t}$.	7|10|8 |10	[20, 215]
CMS measurement of differential tt̄ charge asymmetry, $A_C(m_{t\bar{t}})$ in the dilepton channel.	3	[216]
ATLAS inclusive measurement tt̄ charge asymmetry, $A_C(m_{t\bar{t}})$ in the dilepton channel.	1	[217]
ATLAS & CMS combination of differential tt̄ charge asymmetry, $A_C(m_{t\bar{t}})$, in the ℓ+jets channel.	6	[21]
CMS $t\bar{t}$ double differential distributions in the dilepton channel. $\frac{d\sigma}{dm_{t\bar{t}}dy_t}$ | $\frac{d\sigma}{dm_{t\bar{t}}dy_{t\bar{t}}}$ | $\frac{d\sigma}{dm_{t\bar{t}}dp_{t\bar{t}}^T}$ | $\frac{d\sigma}{dy_t dp_t^T}$.	16|16 |16|16	[22, 218]
ATLAS & CMS Run 1 combination of W-boson helicity fractions in top decay. f_0, f_L & f_R	3	[23]
ATLAS measurement of W-boson helicity fractions in top decay. f_0, f_L & f_R	3	[24]
CMS measurement of W-boson helicity fractions in top decay. f_0, f_L & f_R	3	[25]
ATLAS $t\bar{t}W$ & $t\bar{t}Z$ cross section measurements. $\sigma_{t\bar{t}W}\|\sigma_{t\bar{t}Z}$	2	[26]
CMS $t\bar{t}W$ & $t\bar{t}Z$ cross section measurements. $\sigma_{t\bar{t}W}\|\sigma_{t\bar{t}Z}$	2	[27]
ATLAS t-channel single-top differential distributions. $\frac{d\sigma}{dp_t^T}$ | $\frac{d\sigma}{dp_{\bar{t}}^T}$ | $\frac{d\sigma}{d\|y_t\|}$ | $\frac{d\sigma}{d\|y_{\bar{t}}\|}$	4|4|4|5	[28]
CMS s-channel single-top cross section measurement.	1	[29]
CMS t-channel single-top differential distributions. $\frac{d\sigma}{dp_{t+\bar{t}}^T}$ | $\frac{d\sigma}{d\|y_{t+\bar{t}}\|}$	6 |6	[30]
CMS measurement of the t-channel single-top and anti-top cross sections. σ_t | $\sigma_{\bar{t}}$ | $\sigma_{t+\bar{t}}$ | R_t.	1|1|1|1	[31]
ATLAS s-channel single-top cross section measurement.	1	[32]
CMS tW cross section measurement.	1	[33]
ATLAS tW cross section measurement in the single lepton channel.	1	[34]
ATLAS tW cross section measurement in the dilepton channel.	1	[35]